NEWSLETTER

WOCE

World Ocean Circulation Experiment

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Features

News from WOCE-IPO

Since the last Newsletter, two meetings of importance to international WOCE planning have taken place. One, the Core Project 2 Planning meeting, which was held in Bremerhaven in May, is reported on elsewhere in this issue. The other, the meeting of the SSG at IOS, Wormley in April, dealt with a number of issues of importance, some of which are mentioned here.

As usual the agenda of the SSG addressed a variety of items necessary to keep the planning of WOCE on track. These included the Core Project meetings, reports of committees on geochemical tracers, numerical modelling, and technological developments, consideration of initial plans for data management, reviewing the situation concerning satellite missions, how to prepare the Implementation Plan in early 1987, etc., Mel Briscoe reported on a survey of current meter resources and suggested mooring locations for WOCE. It is also to be found elsewhere in the Newsletter.

The question of obtaining surface fluxes for WOCE received special attention. A meeting had been held at the European Centre for Medium Range Weather Forecasting to address the potential advantages to be obtained by inserting near-surface, real-time meteorological measurements (some obtained from satellite data) into forecast models run by operational centres in order to extract diagnostic fields of surface heat, momentum and fresh water fluxes. Initially, the objective would be to stimulate research on the feasibility and value of such an approach and to reserve the possibility for later doing this with the operational centres and satellite agencies. The report of this meeting will appear in the WCP series. It was decided since this problem extends beyond the interests of WOCE, it could be useful for JSC and CCCO to form a joint working group to pursue the matter further. Terms-of-reference have been drawn up and are being pursued

in the appropriate channels.

Another matter of concern to the SSG was how to support the hydrographic-geochemical tracer programme with ships and laboratory facilities. A working group had considered the matter and their report was available for the SSG. It emphasized the need for a highly coordinated approach to the collection of global hydrographic and tracer data. Few institutions or nations could contemplate collection and analysis of all the quantities expected to be part of the global base programme which, on the basis of the US sector reports, was estimated by the working group to require 7 to 8 years ship time. Collection of the data by a large number of ships used for short periods of time would create many problems regarding data quality and uniformity. The case could thus be made for the use of a small number of ships for extended periods of time using, to some extent, a single dedicated group of technicians. The working group provided a framework for managing and carrying out this programme which, for convenience, has been named R.V. WOCE. However, different countries have different structures for providing ship support and different groups of scientists and institutions have different degrees of concern over placing themselves, and the ships available to them, under a given management structure. Although the benefits of close cooperation were clear, some concerns were expressed about the relatively centralized management structure suggested by the Working Group. Discussions are continuing between national committees, scientists, the SSG and the Working Group to find ways of accommodating all interested parties in a programme meeting the standards of data quality necessary for the success of WOCE. That the ship time needed for the base programme (7-8 years) might be made available by nations was subsequently apparent from the deliberations of the informal Intergovernmental Planning meeting for the whole WCRP held in Geneva in May.

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Seasonal Variability of the Gulf Stream as observed from Satellite Altimetry

A major objective of WOCE is to determine and understand ocean variability on a wide range of space and time scales. Satellite altimetry has been considered an effective global observational tool for achieving this objective. In this note we demonstrate that even with a rather crude altimeter (Geos-3), one can clearly detect the seasonal variability of the Gulf Stream. Only a brief synopsis of the study is presented here. A more detailed description will appear elsewhere.

Using Seasat altimeter data, Fu and Chelton (1985) have demonstrated the utility of altimetric crossover differences (the differences between measurements made at the ground track intersections) in studying the temporal variability of ocean currents. We applied the same method to the 3.5 years of Geos-3 altimeter data (April 1975 – November 1978) to examine the seasonal and interannual variabilities of the Gulf Stream. Due to the limited data acquisition of Geos-3, the western North Atlantic is the only geographic region where nearly continuous data are available.

The advantage of Geos-3 over Seasat is its much longer duration (Seasat lasted for only three months), but its disadvantage is much poorer accuracy. The instrument noise is a factor of 5 worse than that of Seasat, 25 cm vs 5 cm (rms) for 1-sec averaged data. The rms orbit error of Geos-3 is about 2 m, vs 1 m for Seasat. In addition, the Geos-3 data have not been corrected for the effects of tropospheric water vapour, ionospheric free electrons, and atmospheric pressure loading. To recover oceanic signals from such a noisy data set is quite a challenge. Fortunately, most of the errors (except instrument noise) are of scales much longer than the width of the Gulf Stream and can be reduced without compromising the signals associated with the variability of the Gulf Stream. The instrument noise,
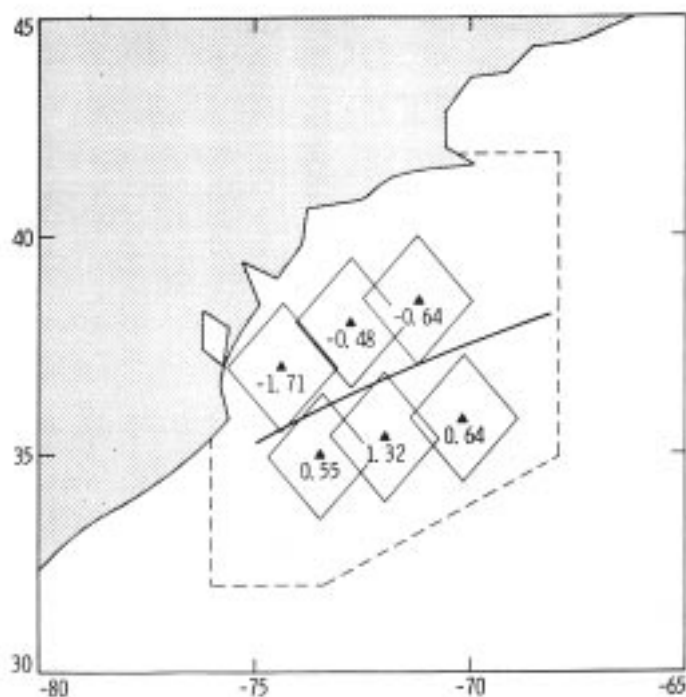
Figure 1. Dashed lines indicate the area where the bias adjustment for reducing long-wavelength errors is performed. Triangles indicate the locations where sea-level time series (spatially averaged over the diamond-shaped areas) are computed. The values of the first EOF are indicated next to each triangle. The solid line segment represents the mean path of the Gulf Stream.

size of the diamond is dictated by the requirement for sufficient data coverage and error reduction. The rms error for the resulting time series is estimated as 5 cm.

To extract the dominant coherent signals from the six time series, an empirical orthogonal function (EOF) analysis was applied to them. The first EOF whose values (normalized) are indicated in Figure 1 accounts for 34% of the total variance. Its spatial pattern is basically an across-stream tilt in sea-level, reflecting the variability of the surface speed of the Gulf Stream. The time variation of the associated sea-level difference (south minus north) across the Gulf Stream (averaged over the three across-stream pairs of diamonds) is displayed in Figure 2. An increase in the difference corresponds to an increase in the across-stream average of the surface speed of the Gulf Stream (10 cm roughly corresponds to 3 cm s^{-1}. A quasi-annual signal can be clearly seen in the time series. The solid line in Figure 3 is the averaged annual variation of the sea-level difference (values in Figure 2 averaged by the months of the year), superimposed on an assemblage of hydrographic observations (dots) of the Gulf Stream transport relative to a depth of 2000 m (from Worthington, 1976). The

however, can be reduced by spatial smoothing along track.

In the region enclosed by dashed lines in Figure 1, the long-wavelength errors (predominantly orbit errors) were modelled by a constant bias along each ground track. These biases were determined to minimize (in a least-squares sense) the residual crossover differences in the region. The residual crossover differences were then sampled in the six diamond-shaped regions. Each side of a diamond is parallel to a ground track and has a length of 200 km. The residual crossover differences in each diamond were first smoothed in both space and time over a 40-day window (see Fu and Chelton for details) and then used to construct monthly time series of sea-level variations. Each time series represents variations of the spatially averaged sea-level within a diamond. The

Figure 2. Sea-level difference across the Gulf Stream (south minus north) versus time, showing the time variation of the first EOF. The mean, whose absolute value is undetermined by the analysis, has been removed.
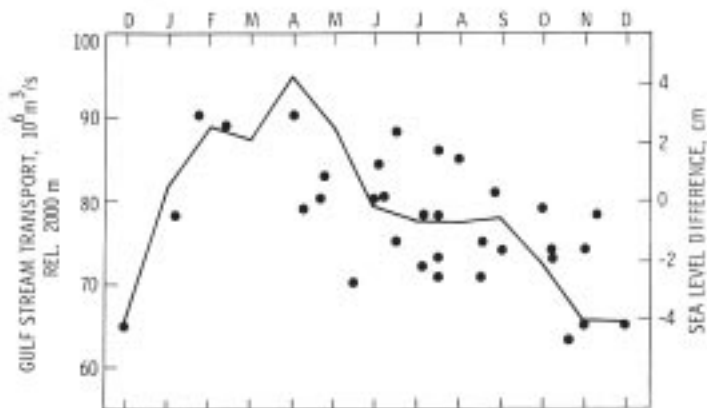
Figure 3. The solid line represents the annual variation of the sea-level difference across the Gulf Stream (values in Figure 2 averaged by the months of the year). The dots represent an assemblage of in-situ measurements of the transport of the Gulf Stream relative to a depth of 2000 m, using hydrographic sections from Chesapeake Bay/Long Island to Bermuda (from Worthington, 1976).

scale and origin for the sea-level difference were chosen to make a good fit between the two observations. The altimetry results are in good agreement with Worthington's findings of a late winter/early spring intensification of the Gulf Stream. Direct measurements of the Gulf Stream transport reported by Halkin and Rossby (1985) also show a similar seasonal behaviour.

This study delivers the first continuous multi-year measurement from space of the variability of the strength of the Gulf Stream, in terms of its across-stream sea-level difference. It is also the first product showing seasonal variations in the ocean from satellite altimetry. These results have demonstrated the potential utility of the precision altimetry from the Topex/Poseidon mission (planned to be launched in May, 1991), which will carry an altimeter with accuracy and precision better than Geos-3 by more than an order of magnitude.

The crossover-difference method should be particularly useful for analyzing the data from the Geosat altimeter (a Seasat class altimeter launched by the U.S. Navy in March, 1985), because the spacecraft has been placed in a non-repeating orbit. Although the sea surface height data from the mission are classified, according to the U.S. Navy, crossover-difference data will be released to the research community in the near future. By applying the method to the data, one could anticipate obtaining monthly maps of global sea-level variations with an accuracy of 5-10 cm.

References

Fu, L.-L. and D.B. Chelton, Observing large-scale temporal variability of ocean currents by satellite altimetry: with applications to the Antarctic Circumpolar Current, J. Geophys. Res., 90, 4721-4739, 1985.

Halkin, D. and T. Rossby, The structure and transport of the Gulf Stream at 73°W, J. Phys. Oceanogr., 15, 1439-1452, 1985.

Worthington, L.V., On the North Atlantic Circulation, 110 pp. , The Johns Hopkins University Press, Baltimore, MD, 1976.

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Lagrangian Floats and Drifters in WOCE

Introduction

In recent years there have been major advances in the technology of unattended, free-drifting ocean instruments. The use of such instruments has become logistically attractive because the substantial costs of moorings are avoided, deployment is simple and minimizes ship operations, recovery is not necessary, and data can be transmitted to shore almost immediately. Additionally, when constructed to follow currents, free-drifting platforms provide the only economical method for directly observing the large-scale, low-frequency velocity field on a global basis. Such direct velocity observations are complementary to other, indirect observations of circulation (i.e. dynamic heights and tracer pathways), but in my opinion they are of irreplaceable value in meeting the objectives of WOCE.

Two types of current-followers will be discussed here: surface platforms supporting drogues which force them to move with the near-surface currents (DRIFTERS) and sub-surface bodies which are neutrally buoyant and drift passively at a selected pressure or isotherm (FLOATS). The schematic plan which follows is of global perspective and limited detail. Several assumptions underlie this plan: the majority of deployments will be made from ships whose tracks are planned for other purposes; platform location and data relay will continue to be possible through System Argos; and instrument developments now in progress will continue and come to fruition before the start of the WOCE Intensive Observation Period.

Instruments

The oldest type of float with long-distance acoustic tracking is SOFAR. The float contains a sound source which can be detected by receivers at distances up to about 2500 km. Lifetimes of five years are feasible for the floats, while the moored or drifting receiving stations must be serviced or replaced at approximately yearly intervals. Because of equipment and deployment costs, a global acoustic tracking network appears to be too expensive for WOCE.

Another acoustically tracked float is RAFOS in which the positions of acoustic source and receiver are reversed between float and mooring. Trajectory data are transmitted from the floats to satellites when they return to the surface after a specified interval at depth. RAFOS floats are much smaller than SOFAR, which eases their deployment and lowers their cost. Multiple cycles seem feasible by combining the present RAFOS system with a more sophisticated vehicle, and five-year lifetimes for such a system are expected. The mooring requirements and costs for RAFOS and SOFAR are similar. Altogether it seems likely that a RAFOS experiment would be perhaps 20% cheaper than an analogous SOFAR one.

Another type, pop-up floats, cycle between the surface, where they are located by satellite, and a specified sub-surface depth, where they drift for a fixed interval without tracking. This eliminates the accompanying acoustic tracking networks (saving expense and achieving geographic freedom), but with an information decrement of less frequently sampled trajectories. Proposed cycle time and lifetime are, respectively, one month and five years; the most stringent limitation will be the number of cycles, now estimated as 50 for mid-depth operation and less for near-bottom operation. Operational unit costs will be about half those of RAFOS.

The motions of Lagrangian DRIFTERS provide measures of horizontal velocity near the surface. Because of wind and wave forces and larger current shear, accurate current-following is more difficult to achieve with drifters than with floats. Substantial technical developments are being made with the

following goals: cheaper transmission using less power and transmitting less frequently; smaller size permitting easier deployment, including from aircraft; greater durability, particularly of the drogue element; simplicity in design for efficient manufacture; and greater current-following accuracy, with adequate calibration to demonstrate this and to permit post hoc correction from knowledge of the wind and wave fields. A target lifetime is 3-5 years. Unit operational costs per data year will be less, and perhaps much less, than for pop-up floats.

Data Sets for WOCE

observations of the large-scale, low-frequency horizontal velocity, and of the variability about it, are essential to any description of the general circulation and to estimations of the transport of properties by it. Floats and drifters are uniquely valuable tools for direct measurement of the velocity field. Other direct velocity measurements can be obtained from moored current meters and shipboard or drifter acoustic velocity profilers. These, however, require considerable overhead in deployment and unit equipment costs and are incapable of giving the combination of extensive temporal and geographic coverage provided by floats and drifters. Less direct estimates of velocity during WOCE will come from altimetric measurements of geopotential height at the sea surface (sea-level) and from hydrographic measurements of its vertical derivative in the interior. Altimetry provides high temporal and horizontal resolution, but, in the absence of an accurate geoid, only yields velocity time changes. It also fails to include the wind-driven velocity component in the surface boundary layer. Hydrography provides the primary vertical resolution of velocity for WOCE, but requires knowledge of velocity at a reference level to recover velocity from geostrophic shear (and, because of the high correlation between surface geostrophic velocity and geostrophic

shear across the thermocline, a surface reference level yields relatively inaccurate estimates of mid-depth or near-bottom velocity); also the resolution of hydrographic arrays will be sparse, particularly in time. Finally chemical tracer concentrations provide indirect evidence of the circulation, but they can only be interpreted within models which still have important inadequacies.

Floats should be used, at a minimum, to determine the absolute, low-frequency velocity fields at one level over the global ocean. For the reason given above, this level should be beneath the thermocline. Near the equator the techniques based on geostrophy fail and floats should be used to determine velocity at several levels. Similarly, in specific regions of particular interest, where increased spatial and temporal resolution is needed, dense acoustically tracked float arrays on more than one level will be required. Important experimental design questions for floats are the choice of vertical levels, the locations for the acoustic tracking networks, the relation of float trajectories to other sources of geostrophic circulation data in creating a composite analysis field, and, of course, the desired sampling densities.

Lagrangian drifters have many of the same advantages as floats. However, for near-surface velocity, other measurement techniques are of similar value in WOCE. Both hydrography and sea-level are useful in estimating surface geostrophic velocity. Acoustic Doppler profilers measure total velocity. Although drifters yield broader coverage with time averaging at lower cost, profilers provide vertical resolution which can be important in this zone of strong vertical shear. Finally, boundary-layer horizontal transport (the vertical integral of low-frequency velocity minus the geostrophic component) can be estimated from surface stress data. Nevertheless, the behaviour of the surface layer on general circulation scales, in particular, the role of its ageostrophic horizontal transport is of such central importance to the objectives of WOCE, and the complexity of its physical processes is so great, that

several complementary and partially redundant measurement techniques should be widely deployed. Important experimental design questions concern the drogue type and depth interval to be spanned, the desired sampling density, and the schemes whereby the variety of surface layer measurements (geopotential heights, velocities, hydrographic profiles, and surface fluxes) can be combined to describe the layer as a whole.

Deployments

A general discussion follows of how the necessary number of floats and drifters is to be determined. It considers only the simplest of analyses (low-order statistics, low-frequency maps) which will be made in WOCE. It undoubtedly gives insufficient attention to regional deviations from global generalities, as well as to how much redundancy should be included to protect against instrument failure.

The deployment of floats and drifters differs from conventional arrays in that, once launched, they move in only partially predictable ways. They are well suited for broad areal coverage, and poorly suited for point measurements. It is a great logistical advantage that current-followers rapidly (on a recirculation time) become fairly uniformly distributed within an ocean gyre and only move slowly into adjacent gyres, thus allowing rather localized deployments when the instrument lifetime is sufficiently long.

The accuracy of the velocity description from current-followers is determined by two factors: instrument bias and sampling uncertainty. Drifter biases arise from wind and wave forces acting on the surface element and drogue tether; a bias of 1 to 3 cm s^{-1} is a realistic, if as yet undemonstrated, target. Float biases result from an inability to follow high-frequency vertical motions due to internal waves; its magnitude should be no more than 3 mm s^{-1} (Davis, unpublished). The critical factor determining sampling uncertainty is the Lagrangian integral time scale Ti. From a long continuous record of length Tr, the uncertainty of estimates of mean velocity, U, and its variance, E, are approximately

$$dU=[E \; Ti/Tr]^{0.5} \text{ and}$$
$$dE= E[Ti/Tr]^{0.5}.$$

The fractional sampling uncertainty for diffusivity is essentially the same as for variance.

Determining Ti is difficult since it is related to the Lagrangian frequency spectrum at zero frequency. However, there is accumulating evidence about Ti from drifter, float, and numerical model observations which, remarkably, all indicate a value, which is quite uniform horizontally and vertically, near 15-20 days, (note the Ti used here is based on a double-sided time integral of the correlation function). The desired absolute accuracy in the mean varies spatially: near the surface in western boundary regions a 3-5 cm s^{-1} accuracy might suffice but at mid-depth in a gyre interior an accuracy an order of magnitude smaller is more appropriate. For comparison, velocity variability is of the order of 50 cm s^{-1} in the former location and 3 cm s^{-1} in the latter. Thus, the required dU, as a fraction of E$^{0.5}$, is geographically fairly uniform, and will result from 100 independent observations, or 5 data years. The same number of observations will give a (dE/E) of 0.1, which is probably better than is required.

The sampling requirements for pop-up floats, which are located only at intervals of the cycle time, Tc, are slightly different. Since these automatically provide the mean velocity over Tc, no information about U is lost as long as the float displacement during one cycle does not exceed the desired spatial resolution of the analysis. Only the variance Ec of the velocity average over Tc can be computed, and the fractional error of both this and the diffusivity estimate is 1/Nc, where Nc is the number of cycles observed. Thus the error in diffusivity from pop-ups exceeds that from a continuously tracked float by the factor [Tc/Ti]$^{0.5}$. With a Tc of one month, this penalty is not large. The primary drawback of pop-ups is their inability to determine E directly; rather, the diffusivity (E Ti) is

measured, with an accuracy only slightly degraded from continuous tracking.

In the case of the single-level global survey, a target spatial resolution would be that which will be obtained from hydrography using existing data and that from WOCE. On a global basis it is perhaps possible to map dynamic height variations on a scale of 500 km. It is desirable to increase resolution in regions with shorter scales of inhomogeneity in U and E (e.g., near boundary currents), although this is difficult because of the long-time tendency for current-followers to become uniformly distributed. There are roughly 1500 resolution cells of $(500 \text{ km})^2$ for the world ocean, which would be filled with the desired analysis accuracy by 1500 floats lasting 5 years. At the surface perhaps twice this number would be required if lifetimes are shorter; if not, then the analysis resolution could be increased to better match that of other surface quantities.

Near the equator, the failure of geostrophy dictates the addition of another interior level (300 floats, say) and the shortness of inhomogeneity scales at the surface requires augmented resolution (350 drifters, say, in each of two settings). Also, at least one single gyre or region probably should be studied with increased resolution to test hypotheses of presumed global relevance. If this region were to cover 20 million square km (half the North Atlantic or the whole of its subtropical gyre), it would require approximately 300 current-followers per level to achieve 250 km resolution. A complement of 600 floats and 300 drifters would provide well measured velocity at three levels.

Discussion

The total numbers described above are 1800 pop-up floats, 600 acoustically tracked floats, and 4000 drifters. The primary decisions which could reduce these estimates would be to decrease the coverage area or to coarsen the resolution. Decreasing resolution would result in a serious loss of information wherever the analysis area spans

significant statistical inhomogeneity in the velocity field, and it is inconsistent with the objectives of WOCE to retreat from global coverage.

There are, of course, many practical issues of manufacture, deployment, tracking, and data handling associated with such a large float and drifter programme. However, the instruments are relatively simple ones and the data volume, limited by the requirements of satellite transmission, is not large compared to other components of WOCE. Since participation in the float and drifter programme can be made not very demanding technically, many different scientists, laboratories, and nations have the opportunity to join in.

(This article was adapted from the Drifter and Float Plan in US WOCE Planning Report No 3. The original was written primarily by Russ Davis and James McWilliams).

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The Core Project 2 Planning Meeting, Bremerhaven, May 20th-23rd, 1986

Introduction

Three Core Project Planning Meetings are to be held in 1986 so that detailed experimental designs and estimates of the resources needed may be available for each Core Project for inclusion in the first WOCE Implementation Plan to be completed in early 1987.

The first of these meetings, on Core Project 2, the Southern Ocean, took place at the Alfred-Wegener Institut at Bremerhaven, FRG from May 20 to 23. Roughly 45 scientists from 13 countries and a wide variety of specialties attended and participated in developing the WOCE plan for the Southern Ocean. The meeting, which was chaired by Jim Crease, opened with a number of papers on the oceanography of the Southern Ocean and on the application of experimental techniques that will be available during WOCE. Working groups then discussed circumpolar circulation, meridional fluxes and ocean-atmosphere exchanges.

Presentations

Arnold Gordon opened the meeting with a wide-ranging overview of the oceanography of the Southern Oceans which set the stage for much of the discussions to follow. His talk both emphasized how much is unknown about processes in the Southern Ocean and, perhaps, somewhat paradoxically how firm a base of knowledge exists on which to base the Southern Ocean Experiment of WOCE. He emphasized the role of the westerlies that provide a stress of about 2 dynes cm^{-2} over extensive sectors and which provide momentum which must be dissipated by, as yet, undetermined processes. The wind stress also produces Ekman divergence (upwelling) to the south of the Antarctic Circumpolar Current (ACC) and convergence (sinking) to the north. The magnitude of the upwelling is about 45 Sv of which about 2/3 goes north and the rest towards Antarctica. Estimates of the ocean/atmosphere heat flux have large errors that partly arise from lack of meteorological information and sea-ice characteristics. Estimates of the ocean heat flux indicate that a flux of 3.1×10^{14} watts is carried south across the polar front by the mean flow, eddy fluxes or Ekman transports. Since the Ekman flux is to the north (1.5×10^{14} watts) the mean flow and eddy fluxes must carry 4.6×10^{14} watts south. How this is done is far from clear.

The ACC, which is estimated to have a transport at Drake Passage of 125 Sv ±10%, displays significant variability with longitude and is apparently strongly influenced by bottom topography, in some places following the flanks of the mid-ocean ridges and elsewhere flowing through the fracture zones. In Drake Passage 70% of the flow is baroclinic. In some places the ACC splits into several filaments. It remains to be determined whether this is a general property. The filaments are marked by fronts which separate various water mass zones to depths of 1000-2000 m.

South of the ACC the baroclinic structure is weak and the wind field regionally drives a poleward Sverdrup transport that is balanced by northward boundary currents at the western side of the three subpolar gyres, the largest of which is the Weddell Sea Gyre. These gyres are the primary sites for the water mass modification that arises from a complicated balance that includes transport of water in and out of the gyres, convective processes, and sea-ice growth, decay and transport. Water-mass formation and conversion are of course of primary interest to WOCE.

The overview by Arnold Gordon was followed by a number of reviews and discussions of scientific issues. The dynamical balances maintaining the ACC, and appropriate models for it, were discussed by Dirk Olbers, who illustrated his talk with results from the model of the Max-Planck Institut at Hamburg. Mike McCartney talked about water mass formation around the ACC and the coupling

of the ACC with the subtropical gyres. He provided a global perspective on the different roles played by the northern and southern oceans in water mass formation and modification. Bottom water formation was introduced by Peter Killworth, and Arne Foldvik talked about processes in the Weddell Sea sub-polar gyre. Sea ice observations, effects, and models for its growth and decay were discussed by Peter Lemke and Claire Parkinson.

Two experimental techniques were given a special airing. Dudley Chelton analysed the errors in sea surface elevation as measured by satellite altimeters and while optimistic for the future, emphasized the need for development of procedures to control some errors. Sea state bias was identified as needing particular attention. He also emphasized that without special satellite missions to determine the geoid the altimeters expected to be available for WOCE will only be able to provide estimates of the changes of sea-surface elevation. He then provided examples of the use of the repeated track and cross-over methods for obtaining the time-dependent fields. The elimination of tidal effects and the need to cross-calibrate ERS-1 and TOPEX-POSEIDON altimeters was also discussed. Bob Cheney talked about the use of altimeter cross-over differences, especially as applied to the NOAA/NGS GEOSAT Programme which has a non-repeating orbit. Data from this system should soon be available and over the next several years should provide insight into the results to be expected from the more accurate satellite systems available during WOCE. Michel Lefebvre discussed arrangements being made in France and internationally to handle ERS-1 and other satellite data.

The second experimental technique drawing particular attention was that of geochemical tracers, the general use of which was described by Wolfgang Roether. The use of the chlorofluorocarbons was elaborated by Ray Weiss, and Peter Schlosser described the use of stable isotopes (Oxygen-18 and deuterium) for identifying the origin of melt water. All addressed the particular role of tracers in following water masses and identifying and quantifying water mass

formation. All used results from the Weddell Sea to illustrate the points made.

Working Groups

As mentioned above working groups were formed to discuss the Antarctic Circumpolar Circulation, meridional flux and ocean/atmosphere fluxes. Since there was bound to be overlap in the deliberations, the meeting also met in plenary sessions from time to time. As a result, although the working group reports overlap with one another, inconsistencies in their recommended programmes were kept to a minimum.

Working Group 1, The Antarctic Circumpolar Current, was chaired by Dirk Olbers. This concentrated on the dynamical balance of the ACC and on its role in transporting heat and salt. They not only considered what experimental data was needed for testing models of the system, but also how the models themselves should be developed. To meet the objective of measuring interbasin exchanges of heat and salt, the working group proposed monitoring the fluxes of heat, salt and other properties on zonal sections across the three oceans to the north and the gyres to the south of the ACC, measuring the surface fluxes between the boundaries, measuring the transport and heat and freshwater fluxes (baroclinic and barotropic) through Drake Passage, obtaining repeated hydrographic sections between Antarctica and South Africa, and making local estimates of fluxes using moored arrays in selected locations. The group also saw the need to study the filaments present in the ACC at various locations and the effects of bottom topography on it.

The group noted the importance of altimeter measurements and the need to deal with the problems presented by Chelton. In consultation with Working Group 2 a hydrographic-geochemical tracer programme was recommended with station spacing across the ACC small enough to resolve its filamented structure. In order to measure transports in Drake Passage they recommended a mooring programme of similar nature to those

previously carried out there. The possible use of ship-borne acoustic doppler profiling systems coupled with precise navigation system (GPS) for obtaining pressure differences between moorings in Drake Passage or on other long sections was raised. As well as using moorings for the purpose of monitoring the large-scale flow, it was recommended that a number of small arrays should be used to gain information on the statistics and role of the eddy field in regions suspected of exhibiting the variety of conditions to be found around Antarctica. The question of a deep float programme was examined and the desirability of using floats to determine the flow field on scales comparable to the major topographic features confirmed.

Working Group 2, Meridional Fluxes, was chaired by Roland de Szoeke. This addressed the wide issue of meridional transports. Although they approached questions from a particular point of view, many aspects of the observational programme they proposed overlap those proposed by the other working groups. To serve a variety of purposes they recommended a hydrographic-tracer survey (see Figure). This will include a number of individual sections in a "spoked wheel" pattern, some curving to intersect continental boundaries, with close station spacing where necessary, CTD measurements to full depth, and with a full suite of geochemical tracer measurement. These sections would be supplemented by circumpolar quasi-zonal sections both north and south of the ACC. The sections would allow the first complete picture of the property fields for the subpolar-ACC subtropical Southern Ocean system, including mapping the expansion of streamlines between the "choke" points around Antarctica. The vertical resolution of CTD measurements would allow potential vorticity mapping down to fine structure scales and the mapping of oxygen, nutrients and geochemical tracers for the first time. This number of quasi-meridional sections is needed to resolve the basin-scale warm water to cold water conversion process, to provide constraints on the east-west changes in mass, momentum and energy fluxes for models, and to map the

geostrophic veering with depth of the ACC system.

The Working Group also considered the role of the subpolar gyres of the Southern Ocean, especially the Weddell Sea Gyre. The dynamical balances of the gyres remain to be determined, for example, whether they are in Sverdrup balance with a western boundary current.
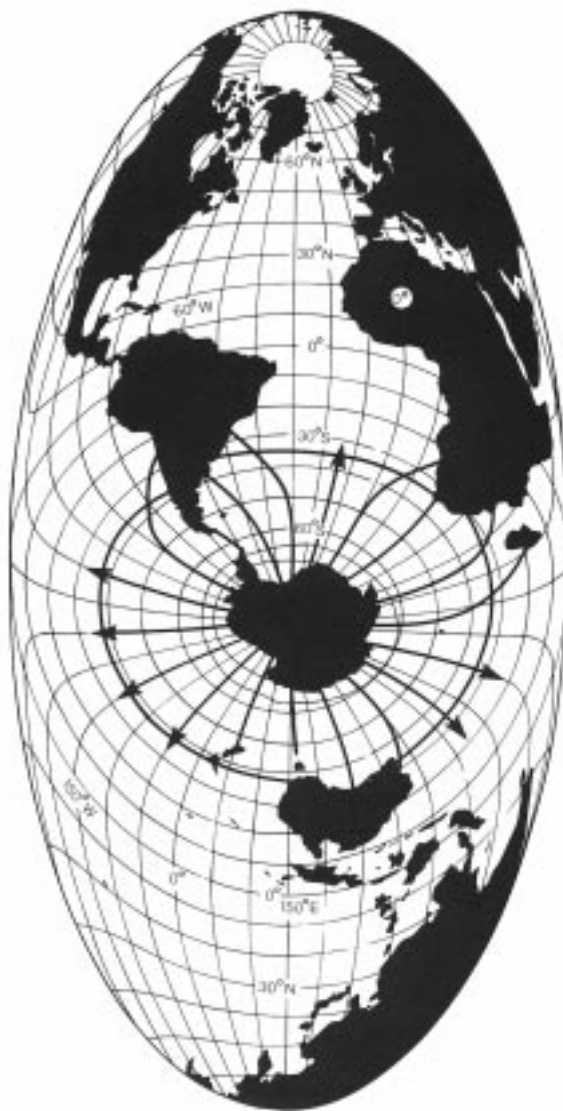
The Weddell Sea of course is the main producer of Antarctic Bottom water, the northward flow of which is important for understanding the heat flux. It was proposed to study the production by measuring the overflow at the still of the Filchner Depression, the outflow of Ice Shelf water at the Filchner Barrier, the deep boundary current on the

northwest slope of the Weddell Sea and the coastal current in the southwest. In Drake Passage it is known that there exist significant eddy fluxes of heat and freshwater. It was proposed to use arrays on 3 or 4 moorings to measure eddy activity in five or six of the "hot spots" indicated by various measurements around Antarctica. Comparison with altimeter measurements during WOCE could lead to putative relationships between eddy heat flux and altimeter variability. Deployments of 4-5 years were seen as necessary for extraction of statistically reliable estimates.

Working Group 3, Air-Sea Interaction considered the all important question of the surface fluxes of momentum, heat, water, etc. They reviewed the existing information of and the expected improvement in knowledge of the wind-stress using scatterometer measurements from NSCAT and ERS-1. These seem to be adequate for WOCE purposes. As elsewhere the surface fluxes of heat and water will be less well-determined by satellite measurements. This could however be improved by measurements from surface drifting buoys and the analyses from atmospheric-general circulation models. The latter depend to some extent on the input of good data from available research and supply ships and this was recommended along with a drifter programme.

The working groups noted the importance of sea ice around Antarctica. It serves as an insulator restricting exchanges of heat, mass and momentum between ocean and atmosphere, changes surface albedo, induces downwelling by salt rejection, and transports a significant quantity of cold-fresh water away from Antarctica. Sea-ice extent can be monitored by satellites using microwave instruments but its movement cannot be (except in particular circumstances using SAR). Thus, a programme of Argos-tracked drifting buoys launched on the ice was recommended. Because of the dependence of the surface flux of heat on ice thickness, both measurements and modelling directed to determining this parameter were recommended.

Modelling

The meeting noted the lack, at present, of an adequate model of the Southern Ocean and recommended that a hierarchy of circulation models be created. The most complex and costly would be an eddy-resolving model with detailed topography and coastline. It would need realistic surface stresses and thermohaline forcing. Ice cover would need special attention and it might only be possible to use climatological seasonal averages.

Simple models are required both as interpretive aids and to concentrate on particular processes. Modelling will also be necessary to fill in what will always be a sparse observational network using a combination of assimilative and time-dependent inverse modelling.

Conclusions

The above presents an overview of the wide-ranging discussions that took place at the Core Project 2 meeting; many details have been ignored. More detailed writeups of the presentations are being prepared and working group reports written. A coherent summary is being prepared and attempts are being made to examine the recommended programmes and to assemble more detailed experimental designs and lists of resources. These should be taken into account when designing the global experiment at the Core Project 3 meeting in November. The results of all the Core Project meetings will be reviewed by the SSG when it meets in December. Much of what has been recommended for Core Project 2 will appear in the WOCE Implementation Plan to be prepared in early 1987. It is to be hoped that many of those participating in the meeting will find the opportunity to participate in the resulting field programmes and analyses.

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Survey of Long-Term Mooring Sites and Current Meter Resources

This note reports on informal (and surely incomplete) surveys of "favourite sites for possible long-term moorings," and on current meter and acoustic release resources that exist in the "global" research community. The two surveys were made independently and were performed mainly on Telemail, so they should be interpreted as being underestimates of the available ideas and resources.

The motivation for the surveys was to see if there was any convergence of opinion about the kinds of long-term moorings that might be useful to a programme like WOCE, to see if the suggested locations of the moorings were few or many, and to see if the resources were consistent with the needs. If the investigators of WOCE were to demand 500 simultaneous current meters in the ocean, and only 400 available instruments exist, then we ought to know so we can plan accordingly. This "sizing of the problem" is herewith reported.

Site Survey

The initial request for long-term mooring sites went out on Telemail in January 1985. By April 1985 suggestions for about 63 locations plus one large array had been received, some by Telemail, some by post, some by word of mouth. The sites are listed in Table 1, including the sort of science they are associated with and the approximate latitude and longitude. There is no significance in Table 1 to the order of listing.

The scientific purposes of the sites proposed fell into several fairly clear categories:
- monitoring deep outflows and inter-basin exchange
- transports in boundary currents
- sites of strong meteorological forcing
- monitoring eddy energy levels (and heat fluxes)

Some of the sites were proposed several times, for example Site 11 in the Agulhas retroflexion region, Site 15 for the exchange between the western Pacific and the Indian Ocean through the Indonesian Archipelago, and Site 36 in the Fram Strait.

The logistic difficulty of the sites varies widely. Site 21 is probably trivial, Site 10 may be intractable. The environmental difficulty varies too, such that some of the sites (e.g., near-surface in the Gulf Stream) are unlikely to be occupied.

In all cases, "long-term" means at least one year, if not 3 years or more. The duration problem is typified by Sites 7-15, which have eddy energies as their purpose; how long a record is needed from these locations? One suggestion was to pick a few of these more difficult but important sites and to begin occupation of them immediately; perhaps in a few years we will then know enough to decide more firmly what is needed at a larger number of locations.

One major problem with some of the locations is that a small or a large array is required: one mooring by itself is more likely to confuse than to inform. The boundary current studies are in this category, the outflow and inter-basin exchanges arguably less so (because the flow is constrained on two sides, not just one).

A final problem is that some of the sites require supporting measurements, for example hydrography, to maximize the yield from the mooring. This makes the logistically more difficult sites even less attractive.

Note that this survey took place before the various planning meetings of late 1985 and during 1986; a few sites should perhaps be added to the list in Table 1 to reflect these meetings, but more importantly some of the sites now have tentative priorities attached to them. Interested scientists could begin to suggest these priorities by providing an updated Table 1.

TABLE 1: SITE SUGGESTIONS FOR LONG-TERM MOORINGS

A. DEEP OUT FLOW FROM THE SOUTHERN OCEAN
1. East of southern tip of Madagascar (near 25S, 48-49E)
2. Eastern edge of Broken Ridge in Southeast Indian Ocean (near 32S, 102-104E)
3. Northeast of Chatham Island on margin of Southwest Pacific Basin (near 42S, 169E)
4. North of Maurice Ewing Bank along southwest margin of Argentine Basin (near 49S, 45W)
5. South Sandwich Fracture Zone [flow into South Sandwich Trench] (near 61S, 22E)
6. Along southern boundary of American-Antarctic Ridge in northern Weddell Sea [westward deep flow] (near 60S, 10W)

B. EDDY HEAT FLUX AND EDDY ENERGY LEVELS NEAR ANTARCTIC CIRCUMPOLAR CURRENT AND IN THE SOUTHERN OCEANS
7-9. Central South Pacific, Atlantic, and Indian mid-ocean positions (near 45S, 140W; 45S, 30W; and 43S, 110E)
10. Southeast Pacific Ocean [quiet, flat region] (near 30S, 105W)
11. Southeast Atlantic near Agulhas retroflexion (near 43S, 12E)
12. Drake Passage (near 62S, 68W)
13. South of Tasmania (near 45S, 147E)
14. Between Kerguelan Island and Amsterdam Island (near 43S, 73E)

C. INDIAN OCEAN-PACIFIC OCEAN EXCHANGE
15. Timor Sea (near 10S, 125E)

D. POLEWARD UNDERCURRENTS
16-19. West coasts of North and South America [climate response and coastal ecosystems] (near 30 and 45N, and 10 and 30S)

E. EQUATORWARD UNDERCURRENTS
20. Under—the Gulf Stream (near 35N) [cross Gulf Stream flow]

F. NORTH ATLANTIC-SOUTH ATLANTIC EXCHANGE
21. East of Trinidad (near 12N, 54W)
22. Fast of Barbados [staircase structures] (near 11N, 55W)
23. East of Brazil (near 3N, 40W)

G. MID-LATITUDE, MID-GYRE
24. Eastern Pacific [for mixing conditions] (near 28N, 155W)
25. Near Hawaiian Ridge (near 30N, 178W)
26. In "dull" center of gyre (e.g. near 30N, and 160W or 60W)
27. Not in "dull" center of gyre (e.g. near 35N, 170W)
28. Eastern Atlantic near Azores (near 32N, 24W)

H. WESTWARD BOUNDARY CURRENTS
29. Gulf Stream (telemetering, for data-assimilative models]
30. Gulf Stream [transport]

I. ATLANTIC OCEAN-MEDITERRANEAN SEA EXCHANGE
31. Strait of Gibraltar [climatic variation] (near 36N, 6W)

J. PACIFIC OCEAN-ARCTIC OCEAN EXCHANGE
32. Bering Strait (near 59N, 179E)

K. DEEP FLOWS INTO THE ATLANTIC OCEAN
33-34. Denmark Strait, Vema Channel (near 67N, 25W) 11N, 44W)

L. ATLANTIC OCEAN-NORWEGIAN SEA EXCHANGE
35. Wyville-Thompson Ridge (near 60N, 8W)

M. ATLANTIC OCEAN-ARCTIC OCEAN EXCHANGE
36. Fram Strait (near 81N, 0W)

N. HIGH LATITUDE METEOROLOGICAL FORCING
37. Labrador Sea [needs conductivity] (near 55N, 54W)
38. Gulf of Alaska/OWS "P" (near 50N, 145W)

O. COASTAL SITES
39-40. North and south of the Mendocino Escarpment [flow into the California Current] (near 39N and 41N, 128W)

P. STRONG METEOROLOGICAL FORCING (ANNUAL AVERAGE)
41. Cape Horn (near 57S, 78W)
42. Cape of Good Hope (near 45S, 15E)
43. South Indian Ocean (near 45S, 60-100E)
44. Central Indian Ocean (near 16S, 90E)
45. Southeastern North Pacific Ocean (near 14N, 158W)
46. Caribbean Sea (near 13N, 77W)
47. East of Somalia (near 10N, 54E)
48. Labrador Sea (near 48N, 42W)

Q. WEAK METEOROLOGICAL FORCING (ANNUAL AVERAGE)
49. Western-equatorial Pacific Ocean near 0N, 140-160E)
50. Central North Atlantic Ocean (near 30N, 45W)
51. Equatorial Indian Ocean (near 0N, 68E)
52. Eastern South Pacific Ocean (near 32S, 120W)
53. South Atlantic Ocean (near 27S, 20W)

R. VARIABLE METEOROLOGICAL FORCING (OVER MONTHS AND LONGER
54. Western North Atlantic (35-55N, 30-70W)
55. Equatorial North Atlantic (near 8N, 50W)
56. Northwestern Indian Ocean (5-20N, 50-70E)
57. Tropical Indian Ocean (near 13S, 50-90E)
58. South-central Indian Ocean (near 40S, 60-90E)
59. Northeastern Indian Ocean (near 5-20N, 85E)
60. South of New Zealand (near 55S, 170E)
61. Western North Pacific Ocean (N. of 35N, W. of 160E)
62. Tropical western North Pacific (near 10-20N, 110-140E)
63. Tropical eastern Pacific Ocean (near 10N, 120-150E)

S. NORTH ATLANTIC EXCHANGES
An array of moorings from Labrador (Cape Harrison) to Greenland (Cape Farewell) to Ireland (Porcupine Bank): the distance is 3000 km, so 30 km spacing would require 100 moorings with lengths varying from 4 km to 0.5 km.

TABLE 2: SURVEY OF GLOBAL (ACADEMIC) CURRENT METER RESOURCES

LABORATORY	NUMBER OF CURRENT METERS				NO. OF RELEASES		NOTES
	VACM	VMCM	AAND	OTHER	EG&G	OTHER	
NOAA/PMEL	45		70				Estimates made by D. Halpern
U. Washington		4	25				Ditto
Scripps		40			12		Also have 5 RD acoustic doppler profilers. Totals include R. Davis and C. Winant
IOS, B.C.			100	20		82	
Other B.C.			4	10		2	Estimates made by R. Thompson, IOS, B.C.: includes U.B.C.
CSIRO, Aust.	1		23	6	10		
COB (IFREMER)			56			24	Typically 7-10 moorings per year
ORSTOM (France)	10						
IFM, Kiel			60	3		8	Typically 8-15 moorings per year. Possible 1990-95 work in the Southern Ocean, the northern North Atlantic and the Brazil Current
Other F.R.G.			30			4	Estimates made by G. Siedler, IFM, Kiel for Bremerhaven and Hamburg
IOS, Wormley	8		50			25	Typically 4-5 moorings per year, 5 CMs per mooring. About 70 percent of resources could be devoted to WOCE
Other U.K.			130			40	Estimates by J. Gould, IOS, Wormley for IOS Bidston, NERC Research Vessel Services, MAFF Fisheries Laboratory and SMBA
SACLANT Centre			40		18		
NC State Univ.			12	4	6		Also has 3 RD acoustic doppler profilers. Typically 12 surface moorings per year
U. Miami/RSMAS	46	6	30		19	7	Typically 8 moorings per year, 8 CMs per mooring
U. Alaska		2	42		12		Typically 6-12 deep moorings per year, or 20-30 shallow
U. Hawaii			7			2	
WHOI Buoy Group	94	37			41		
Japan			99				Estimates by Y. Nagata for Ocean Res. Inst., Kagoshima Univ., Tokai Univ., Inst. of Physics and Chemistry Res., and Tsukuba Univ.
Bedford Inst.			120		60		Typically 50 moorings per year, per year, about half of which could be used for WOCE
Lamont-Doherty		5	17	1			Estimates via S. Garzoli, who also has 7 IESs and may have 9 available for WOCE
Univ. N Carolina			16		7		Instruments in use in SYNOP until at least 1990
Oregon State U.		8	108	10	47		Equipment available for 35 intermediate moorings
Texas A&M			4				
Univ. Delaware				10	8		
TOTALS	204	102	1043	64(1413)	232	202(434)	

Current Meter and Release Survey

In February 1986 I solicited by Telemail information on the maximum current meter, acoustic release, and mooring resources that might be available during WOCE. I also requested early thinking on what commitments had already been made.

Table 2 summarizes the responses received from many sources up through April 1986. The Notes in the table are important: they indicate that some of the numbers are only estimates, and some of the equipment listed is definitely not available for investigations within WOCE, because of other commitments.

Some of the resources listed are useful in shallow water only; I estimate perhaps 20-40 percent is in this category. Most of the equipment shown is reliable only for one-year and shorter deployments: the VACMs will last arguably 2 years.

A generous assessment of Table 2 is that some 1000 current meter-years are available for deep water programmes in WOCE. If half the resources are deployed while half are being turned around and readied for the next deployment, and there are 5 current meters per mooring, then 100 mooring sites can be maintained with the available resources. Some of these 100 are already spoken for in various programmes (e.g., see Note 5 in Table 2).

Note that Table 2 is an underestimate of the existing resources (because the survey was incomplete), but it sizes the problem. For all the large numbers in Table 2, the number of moorings that are realistically available for WOCE programmes is limited.

Conclusions and Suggestions

Tables 1 and 2, taken together, suggest that a wise selection of long-term mooring sites could be maintained with available current meter resources, if all the resources are not tied up in other, perhaps regional, programmes. Because of the potential value of long-term observations to WOCE, those investigators interested in using mooring resources for such studies would be wise to begin their planning now and to begin to schedule their needs.

The uncertainty of how long some of the observational programmes need to be also argues for beginning soon with some early studies in well-chosen sites. Those locations requiring potentially long records can then be initiated while resources are more easily available.

My favorite candidates for an early start for long-term monitoring are (Table 1) Sites 2, 4, 7-9, 11, 14, and 15. The Site 15 suggestion is because of the possible effect of El Nino years on flow through the archipelago, and hence the need for very long time series there. Anybody else have any suggestions?

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ERS-1 Announcement of Opportunity

The WOCE SSG has set up a small working group to help focus the important contribution that ERS-1 will make to WOCE.

Its Terms of Reference are:
1) to serve as a point of contact with WOCE scientists seeking to obtain ERS-1 data, either individually or through membership of investigator teams responding to the ERS-1 A/O.
2) to act as intermediaries for the WOCE-SSG to the various ESA advisory and programme committees which influence the ERS-1 operation, and data processing and dissemination systems.

In addition. the Working Group will maintain contacts to the various N-ROSS and TOPEX/POSEIDON scientific teams and to the proposed WCRP Surface Flux Working Group to ensure that the recommendations and plans of these groups are properly brought to the attention of the appropriate ESA committees.

The members are: J. Crease, K. Hasselmann, M. Lefebvre and C. Wunsch.

If you use Telemail to the committee members a copy to WOCE.IPO would be appreciated. We are here to help.

Comments on the Report of an ad hoc Meeting on Density Profiling, WOCE Newsletter No. 2, March 1986

Terry Joyce has drawn the attention of the WOCE community to shortcomings and future needs of density profilers. The author of this note strongly supports the basic aims of the report, but three items call for deeper discussion.

Firstly, a replacement of (conductivity calibrated) standard sea water presently used as a conductivity standard by a standard (precision) resistor is impossible, because conductivity and resistance from the physical point of view are quite different quantities with different physical dimensions (Ω^{-1} m^{-1}) and Ω. From this dimensional argument it follows, that the resistance R of the water loop around (or within) the conductivity sensor is related to the conductivity C of the sea water by an equation of the form $R = (C.1)^{-1}$ where 1 is a constant with the dimension of a length. 1 depends on the shape and the size of the sensor and is the "cell constant". In general, the cell constant of conductivity sensors for oceanographic in situ applications cannot be determined by a geometrical measurement with the necessary accuracy and as long as this is true, the calibration of the conductivity sensor requires a conductivity standard, not a resistance standard.

Secondly, though the advent of inexpensive computers has de-emphasised linearity and uprated repeatability and sensitivity of oceanographic sensors, it should be pointed out, that preference should be given to those nonlinear sensors, whose calibration curve is describable by a minimum of constants. Worth should be laid to the fact that the calibration curve constants are really constant, i.e. don't depend on temperature and pressure.

Thirdly, it should be noted, that the linear sensor will remain the favourite among all kinds of sensors. The reason is, that only the linear sensor allows time averaging (as well as other kinds of linear filtering) of the measured physical quantity (which serves as input of the sensor) simply by time averaging the sensor output. Any non-linear sensor would require, that the whole time series of the sensor output must be transformed (by applying the calibration curve) into a time series of the sensor input before the time averaging can be carried out.

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I have read with interest the report of an ad hoc density profile group (Terry Joyce, author). I have particular interest in and experience of CTD measurements in the 'deep ocean' and wish to comment on two issues discussed under this heading.

That IOS standard seawater is an imperfect standard I would not dispute. It is a standard of chlorinity and so labelled: since mid 1980 (starting with batch P91) it has also become a transfer standard of conductivity, employing solutions of KCl of known concentration as the standard. Since that change comparisons amongst different batches made by an independent investigator reveal that the range of variation is nearer to ±.001 than the ±.003 mentioned by Joyce. This change is significant if it can be sustained although it will be very difficult to improve. The suggestion by the group that precision resistors have a role to play in the better routine measurement of conductivity is sound especially for bench salinometry. Substituting the conductivity cell for precision resistor at a fixed temperature would separate

changes in the performance of the cell (when standardised by standard seawater) from changes in the rest of the unit – and in the long term reveal where design changes were desirable. The units of conductivity are ohm^{-1} m^{-1} and shows that its determination <u>must</u> involve both resistance AND length measurement, both to order 1-2 parts in 10^5. Thus I see no way of replacing a liquid conductivity transfer standard by a resistance measurement ALONE.

Of the pressure, temperature and conductivity sensors few would dispute that the biggest improvements still need to be made in conductivity. The Joyce report emphasises the need for improved resolution and improved calibration capability. In my experience both are quite minor matters compared to the problems of stability. Stability is both the first and second priority for improved salinity estimates in the deep ocean. Lack of stability is manifest by making repeated casts into the deep ocean at the same location and by examining the displacements of the potential temperature-salinity curves. In addition lowerings made into a deep well mixed bottom layer reveal short term instabilities. Both are ±.001 to ±.002 in salinity with occasional and unpredictable excursion several times larger than this. Even the smaller of these fluctuations is comparable with the signal seen (?) on large scales in the deep NE Atlantic and probably in other 'quiet' oceans too. I don't have any suggestions for improving cell stability - does anyone?

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Japanese - US Workshop on Joint Scientific Efforts in Support of WOCE

Members of the US and Japanese National WOCE Scientific Steering Committees met 20-24 March, 1986 at the Ocean Research Institute (ORI) of the University of Tokyo, to identify areas of possible future co-operation between Japanese and US oceanographers in support of WOCE and to begin planning for such co-operation.

The workshop began with a WOCE symposium which summarized the present objectives of WOCE, reviewed recent scientific efforts relevant to WOCE and identified a broad range of possibilities for future Japanese-US co-operation. The symposium was followed by a planning meeting which focussed on activities of strong mutual interest. Plans were made to advance cooperative work, particularly in areas where a long lead time was required, for example, technology and ship schedules.

It was noted that Japanese interests in WOCE are very broad. They include fluxes of heat and water throughout the Kuroshio region; air/sea fluxes and mixed layer/deep ocean fluxes; gyre dynamics and water mass distribution in the North Pacific; deep ocean circulation including both direct measurements and chemical tracer studies; ocean modelling; data assimilation and development; and application of new technology. Present and planned ocean monitoring in waters near Japan and in the western Pacific probably are adequate to meet WOCE requirements. Some deep-ocean sections could be expanded to assist WOCE if the additional data collected would also be useful for other purposes, such as meteorological forecasting or fisheries.

It was evident that joint bilateral planning would be advantageous with the sharing of information, for example, on data management and technology development in physical oceanography and geochemistry, and the sharing of both personnel and equipment resources for field studies.

The US is presently developing a comprehensive data management system to meet the needs of both WOCE and TOGA

investigators in the US. The key feature of the system is that it is a "distributed" system with data gathering, processing and archiving being spatially distributed among many locations connected by a computer/communications network. The Japanese Oceanographic Data Centre (JODC) is interested in, and might be able to assume, some new responsibilities for WOCE data management in Japan.

The JODC is considering possible new systems to meet a broad range of expected expanding data needs, including those for the World Climate Research Programme. Plans are being developed for a network in Japan for exchange of oceanographic data and it is possible that this network could be linked with the US-WOCE data system. Certain arrangements for the exchange of satellite data between the US and Japan presently exist and these could be developed further to include specific arrangements for exchange and analysis of WOCE-related satellite data, and for the preparation of WOCE data products. A pilot project for exchange of WOCE data inventories has been established in the US, and it was suggested that Japan also should participate in this project.

Both the Japanese and US geochemistry communities are small compared to the scope of the WOCE tracer measurement and technology problem. To develop the new geochemistry technology needed for WOCE, the US and Japanese efforts should be integrated with each other and with those of the international community in general. Of particular importance is exchange of ideas on and collaboration in collection of samples for specialised measurements such as actinium-227, low-level tritium and argon-39. Existing technologies for the measurement of chlorofluoromethanes and isotopes such as actinium-227 and radium-228 need to be exchanged so as to enhance the capability to measure such tracers at the resolution required for WOCE.

Technological aspects of physical oceanography that would benefit from information exchange and collaboration include air-sea flux measuring packages (including improved humidity and radiation sensors); the development of improved but inexpensive automated weather systems for shipboard use; the development, for shallow and deep water applications, of SOFAR floats and acoustic transducers for tomography; the development of moored, bottom-mounted and ship-mounted acoustic doppler current profiling systems; and improvements in CTDs, XBTs, XCTDs, winches, wire and nutrient measurement systems. There also should be collaboration to assure that hydrographic, nutrient and oxygen measurements for WOCE are of the highest accuracy.

Resource sharing will be a vital component of WOCE and will require co-ordination of activities between research and operational agencies both within individual countries and world-wide. It was suggested that there might be WOCE-dedicated cruises by a number of Japanese vessels including the ice-breaker Shirase.

It was agreed at the end of the workshop that joint Japanese-US co-operation in support of WOCE would be extremely beneficial and that it should be further developed with a second workshop in the summer of 1987.

Copies of the full report of this workshop are available from the US Planning Office for WOCE, Department of Oceanography, Texas A&M University, College Station, TX 77843, U. S. A.

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